NASA's Surface Meteorology and Solar Energy Web Portal (Release 6.0)

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ABSTRACT

A primary endeavor of NASA's Prediction of Worldwide Energy Resource (POWER) project is to synthesize and analyze data that is useful to the renewable energy industry on a global scale [1]. One goal of POWER is to provide data to the renewable energy industry in quantities and terms compatible with this industries design and engineering tools and for locations where ground site data is not readily available.

The Surface meteorology and Solar Energy (SSE) data set and web site have been a valuable resource for a growing user community involved in renewable energy. The POWER project continues to improve upon information available via the SSE web site. This paper describes the availability of higher spatial resolution assimilated data in a new release of SSE (i.e. SSE 6.0) that extends the period of coverage to 22 years.

1. EXTENDED DATA SET

The two primary data sources provide higher spatial resolution than the data used in previous versions of SSE. Radiation parameters are provided by the NASA/Global Energy and Water Cycle Experiment (GEWEX) Surface Radiation Budget (SRB) project, also located at the NASA Langley Research Center [2]. Temperature and humidity parameters are based on the Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS) assimilation model version 4 [3]. Data is accessible for every 1° x 1° region over the globe for the time period of July 1983 through June 2005. Monthly averages for the 22-year climatology are at hand. New parameters have been added to provide information required for total integrated renewable energy systems including solar energy.

2. WEB SITE APPLICATIONS

Web applications have been developed to display data in a variety of ways useful to diverse user communities (e.g. solar resources, sustainable buildings, and agriculture). Spatial and temporal views of the data set are available. The user may view global or regional plots (spatial coverage), climatological monthly averaged data tables and lists of daily averaged values. Web site navigation among the multitude of climatological parameters is straightforward. Several applications provide unit conversion tables. The exact location chosen and the relationship of that latitude and longitude to the 1° x 1° region over which the SSE data is representative may be mapped and viewed (figure 1). This may be helpful in determining if a site is influenced by local microclimate variability, possibly from coastal or rugged mountain terrain.

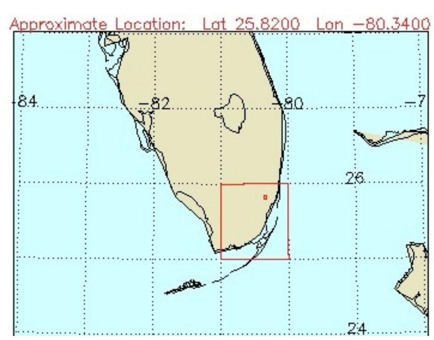

Fig. 1: Example location within a 1° x 1° region

Fourteen radiation and temperature parameters are now included in the daily averaged time series data set for the entire 22-year period. An example is shown in figure 2. A plot of values for a single parameter can be displayed for any time slice within the 22-year period and one or many parameters may be displayed in tabular form. The user may tailor the data output to their needs. Time series data output may easily be copied and pasted into common spreadsheet software.

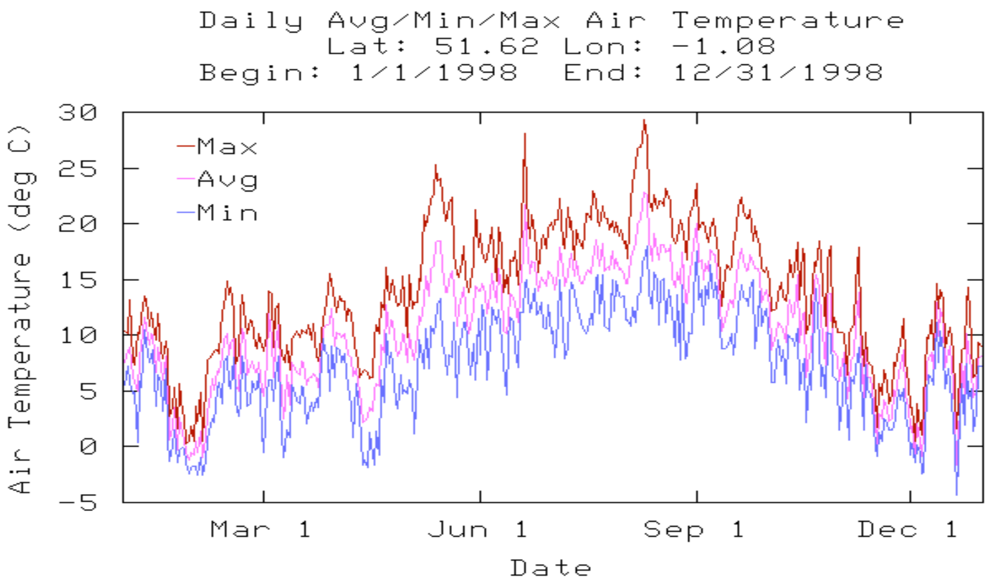

Fig. 2: Daily averaged temperature time series data

The global/regional plot application has been expanded to provide annual averages or sums for many parameters along with monthly averages over the longer, 22-year, climatology (figure 3). There now are monthly averages by year and daily averaged data for the entire 22-year period for many parameters. A code next to each parameter provides the information needed to select the appropriate day, month, and year options. Maps may be made for the entire globe or any region of the globe as small as six by six degrees of latitude and longitude.

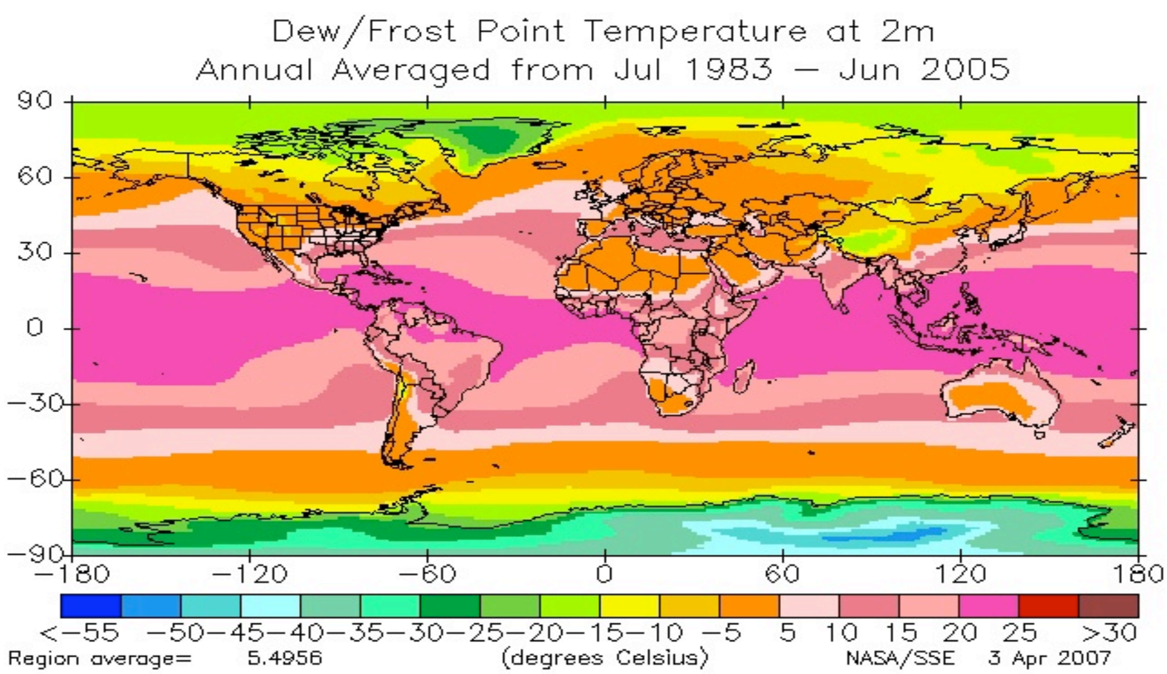

Fig. 3: Global plot of dew/frost point temperature annual averaged over 22 years

3. VALIDATION

The new parameters in SSE 6.0 are derived primarily from meteorological and atmospheric data (i.e. temperature, precipitable water, pressure) available via GEOS-4. Briefly, these parameters are estimated through an atmospheric analysis (i.e. GEOS-4) performed within a data assimilation context that combines information from irregularly distributed atmospheric observations with a model state obtained from a forecast initialized from a previous analysis. The GEOS-4 process seeks to assimilate and optimize observational data and model estimates of atmospheric variables. Types of observations used in the GEOS-4 analysis include (1) land surface observations of surface pressure; (2) ocean surface observations of sea level pressure and winds; (3) sea level winds inferred from backscatter returns from space-borne radars; (4) conventional upper-air data from rawinsondes (e.g., height, temperature, wind and moisture); (5) additional sources of upper-air data include drop sondes, pilot balloons, and aircraft winds; and (6) remotely sensed information from satellites (e.g., height and moisture profiles; total precipitable water and single level cloud motion vector winds obtained from geostationary satellite images). Emerging from the GEOS-4 analysis are daily global estimates of the vertical distribution of a range of atmospheric parameters. The GEOS-4 estimates are initially on a 1° latitude x 1.25° longitude global grid at 3-hourly time (GMT) increments. The POWER project extracts the GEOS-4 temperature estimates for 2 m above the earth's surface, bilinear interpolates the temperature values to a global 1° x 1° grid to be consistent with the solar parameters also provided through POWER, and calculates daily averages at local solar time.

In addition to the validation study reported by the GMAO [3], the POWER project initiated a validation study that was more focused on the applications supported within the POWER project. In particular, the GEOS-4 air temperatures (daily averaged, minimum, maximum and dew point), relative humidity, and surface pressure have been explicitly compared to global data obtained from the National Climate Data Center (NCDC). Data from the NCDC archive were selected using what we characterize as 85% selection criteria. Namely, only data from NCDC stations reporting 85% or greater of the possible one-hourly observations per day and 85% or greater of the possible days per month were included in comparisons with the GEOS-4 derived data. Figure 4 shows the location of NCDC surface stations for 2004 based upon the 85% selection criteria, while table 1 summarizes the agreement obtained when comparing monthly mean values of the NCDC ground site data to monthly mean values of the GEOS/POWER derived data. We note that both the NCDC observations and the GEOS/POWER values are at 2 m above the surface. Also for reference, table 2 gives the accuracies anticipated for observations from NCDC stations [4].

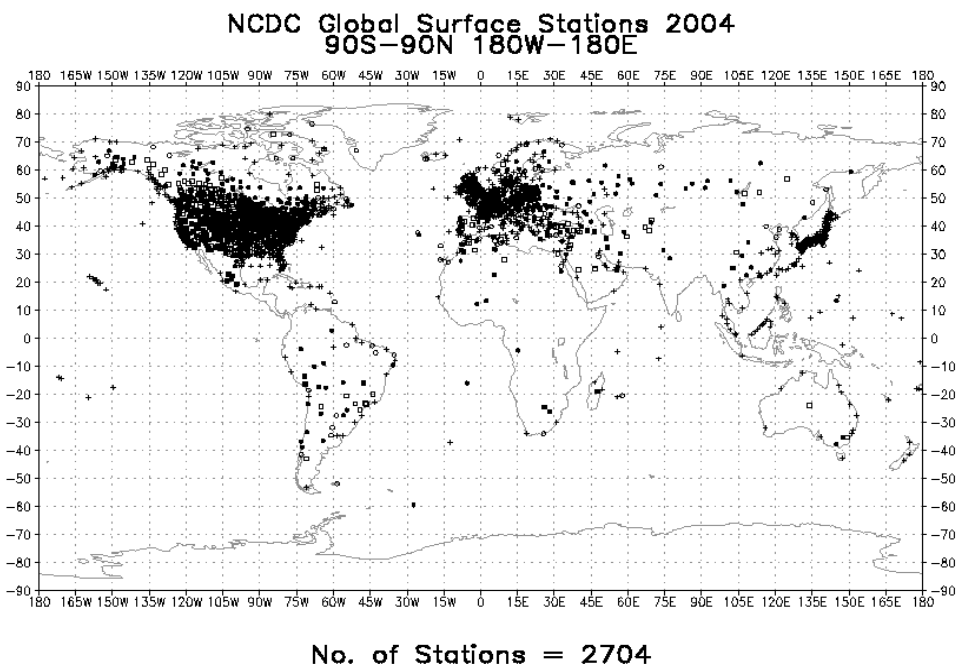

Fig. 4: NCDC stations meeting 85% selection criteria (2004)

TABLE 1: LINEAR LEAST SQUARES REGRESSION ANALYSIS OF GEOS-4/POWER VERSUS NCDC FOR MONTHLY AVERAGED VALUES MEETING THE 85% SELECTION CRITERIA (2004)

	No Elevation Difference Correction					With Elevation Difference Correction				
	Slope	**Intercept**	**R^2**	**RMSE**	**Bias**	**Slope**	**Intercept**	**R^2**	**RMSE**	**Bias**
Tmax	0.99	-1.59	0.95	3.08	-1.77	1.00	-1.30	0.96	2.46	-1.26
Tmin	1.02	0.09	0.95	2.53	0.25	1.03	0.50	0.96	2.29	0.69
Tave	1.02	-0.85	0.96	2.17	-0.60	1.03	-0.49	0.98	1.64	-0.13
Tdew	0.96	-1.05	0.95	2.56	-1.31	NA	NA	NA	NA	NA
RH	0.77	13.18	0.53	9.72	-3.03	NA	NA	NA	NA	NA
Heating Degree Days	1.00	17.38	0.90	90.61	16.50	0.99	8.24	0.91	80.63	6.57
Cooling Degree Days	0.84	2.22	0.92	28.16	-6.14	0.90	3.82	0.93	24.84	-1.43
Atmospheric Pressure	0.83	157.64	0.71	30.37	-9.96	1.00	-3.35	1.00	3.64	0.15
Units for Intercept, RMSE, and Bias: Temperatures in °C, Relative Humidity in %, Heating and Cooling Degree Days in °C-days, Atmospheric Pressure in hPa (NA = not available)										

TABLE 2: ESTIMATED GROUND SITE DATA UNCERTAINTY

PARAMETER	RANGE	ACCURACY
Temperature (°C)	-62 to -50 -50 to +50 +50 to +54	$\pm$1.1 $\pm$0.6 $\pm$1.1
Dew Point (°C)	-34 to -24 -24 to -01 -01 to +30	$\pm$2.2 $\pm$1.7 $\pm$1.1

Note that table 1 lists parameters from a linear least squares regression analysis for temperature values without an "elevation difference" correction and for values with an "elevation difference" correction. For the daily average temperature (Tave), daily minimum temperature (Tmin), and daily maximum temperature (Tmax) the elevation difference correction is an effective "lapse rate correction". The correction applied to the GEOS/POWER pressure values (p) is based upon the hypsometric equation (1), relating the thickness (h) between two isobaric surfaces to the mean temperature (T) of the layer.

(1) $h = z_1 - z_2 = (RT/g)\,ln(p_1/p_2)$ where:

z1 and z2 are the geometric heights at p1 and p2
R = gas constant for dry air
g = gravitational constant

Both the temperature and pressure corrections to the GEOS/POWER data are related to the difference in average elevation of the GEOS/POWER data region and the ground site elevation. Recall that the GEOS/POWER temperature and pressure data are on a global 1-degree grid, where the GEOS/POWER values represent the average over a given 1-degree latitude/longitude region. The "Elevation difference correction" in table 1 refers to an adjustment to the GEOS/POWER temperature and pressure values associated with the difference in averaged elevation of the 1-degree GEOS/POWER region and the elevation of a specific NCDC ground station. Analysis of the biases between the GEOS/POWER and NCDC temperature values and differences between GEOS4/POWER region and ground site elevation, clearly indicate a dependence on the elevation differences for the daily minimum and maximum as well as the daily average temperature. Using the global ensemble of NCDC stations shown in Figure 1, we obtained global lapse rate corrections of -5.4, -5.1, and -5.9 °C/km for the daily average, minimum and maximum temperatures, respectively. As noted above, the GEOS/POWER pressures were corrected using the hypsometric equation. No altitude related corrections are required for dew point and relative humidity values.

The comparison of the "corrected" versus "uncorrected" GEOS/POWER parameters provided in table 1 is given here primarily to illustrate the improved agreement that application of an elevation difference correction affords. Note, for example, that mean biases between the NCDC and GEOS/POWER data are, in general, reduced with the application of the elevation difference corrections. The corrections to the GEOS/POWER surface pressure exhibit significant improvements as evident in the reduced RMSE and Bias. Also, particularly noteworthy is the improved agreement between the NCDC and GEOS/POWER heating and cooling degree days for the corrected GEOS/POWER data. In general the mean GEOS/POWER Tmax values are cooler than the NCDC values, and the mean GEOS/POWER Tmin values are warmer even after application of the elevation difference correction, although the differences tend to be on the order of the observational accuracies attributed to the NCDC data (table 2).

What we have referred to as an "elevation difference correction" tends to be important primarily for mountainous regions. Figures 5a and 5b provide a graphical illustration of the spatial dependence of the differences between the mean values of Tmin and Tmax for the NCDC and uncorrected GEOS/POWER data sets. The mountainous regions of western US clearly exhibit the largest differences between the NCDC and GEOS/POWER temperature. The coastal regions where the 1-degree GEOS/POWER region is too coarse to capture localized ocean/land gradients also tend to exhibit larger differences. While we anticipate that future refinements to this analysis will result in both regional and seasonal dependent corrections, the default condition when downloading temperature data from the SSE-6 data portal is uncorrected, thereby affording individual users the option to apply more appropriate regional/seasonal lapse rate (i.e. elevation difference) corrections when needed. Note that the significant amount of white regions on the maps in figures 5a and 5b indicate locations where there is no NCDC ground site data available.

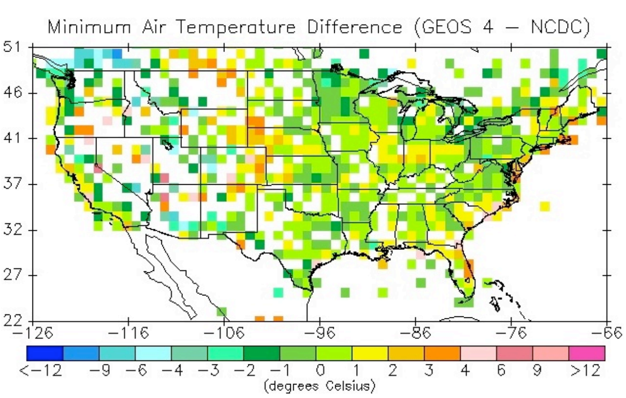

Fig. 5a: Difference between the mean values of Tmin for the NCDC and uncorrected GEOS/POWER data (2004)

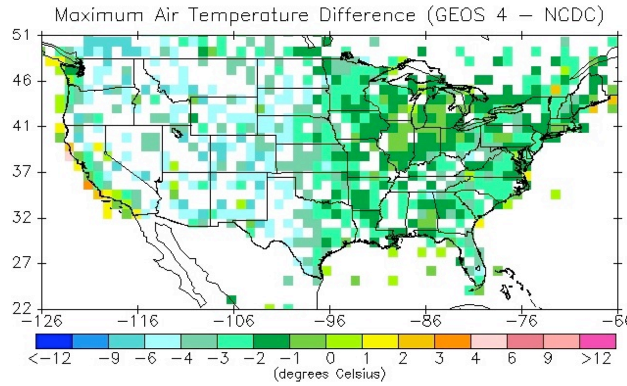

Fig. 5b: Difference between the mean values of Tmax for the NCDC and uncorrected GEOS/POWER data (2004)

4. RENEWABLE ENERGY PROJECT ANALYSIS

SSE has an interface to provide a data stream directly to NREL's Hybrid Optimization Model for Electric Renewables (HOMER) and the RETScreen® International Clean Energy Project Analysis Software. HOMER is used for designing standalone electric power systems that employ some combination of wind turbines, photovoltaic panels, or diesel generators to produce electricity. If a HOMER user chooses to get NASA solar radiation data, the process is done automatically. The HOMER software requests the data without using a web browser. SSE sends an XML document and it is ingested directly into the HOMER software. RETScreen® will be announcing their latest upgrade in the near future. The new version of RETScreen® uses 22-year climatological averages of temperature, relative humidity, daily solar radiation, atmospheric pressure, earth temperature, earth temperature amplitude, heating and cooling degree days, heating and cooling design temperature from SSE.

5. SUMMARY

The Internet address of the free SSE data set and web site is http://eosweb.larc.nasa.gov/sse. The POWER Project has provided a growing suite of data formulated for assessing and designing renewable energy systems anywhere in the world. NASA data may be used to augment ground site data sets plus fill the gap where ground site data does not exist. The POWER project web site (http://earth-www.larc.nasa.gov/power) includes new web applications being developed to provide data useful for sustainable building design and agroclimatology.

6. REFERENCES

(1) Stackhouse, Paul W., Jr., R. S. Eckman, C. H. Whitlock, W. S. Chandler, J. M. Hoell, T. Zhang, J. C. Mikovitz, G. S. Leng, P. Lilienthal, Supporting Energy-Related Societal Applications Using NASA's Satellite and Modeling Data, IEEE International Geoscience and Remote Sensing Symposium, Geoscience and Remote Sensing, Denver, CO, 2006 [available from the “POWER publications” link at http://earth-www.larc.nasa.gov/power]

(2) Cox, S.J., P.W. Stackhouse, Jr., S.K. Gupta, J.C. Mikovitz, M. Chiacchio and T. Zhang, The NASA/GEWEX Surface Radiation Budget Project: Results and Analysis, International Radiation Symposium, Busan, Korea, 2004

(3) Bloom, S., A. da Silva, D. Dee, M. Bosilovich, J.-D. Chern, S. Pawson, S. Schubert, M. Sienkiewicz, I. Stajner, W.-W. Tan, M.-L. Wu, Documentation and Validation of the Goddard Earth Observing System (GEOS) Data Assimilation System - Version 4, Technical Report Series on Global Modeling and Data Assimilation, NASA/TM—2005–104606, Vol. 26, 2005

(4) Surface Weather Observations and Reports, Federal Meteorological Handbook No. 1, FCM-H1-2005, Washington, D.C., 2005